

AUTONOMOUS RF RADIATION PACKAGE FOR VARIOUS APPLICATIONS

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Abstract

The development of an autonomous RF radiation package for various applications is presented. This work is a coordinated effort to develop a tightly integrated unit, including the batteries, power supply, Marx generator, and plug and play antennas for various applications.

ARC Technology has designed the Marx generator and its associated high voltage antennas for this effort. Previous work by ARC has demonstrated 75 mm diameter, 700 mm length diameter Marx generators capable of delivering 200 kV pulses into 50 Ω coaxial cable with sub-nanosecond risetimes, enabling it to drive an antenna and generate high power microwaves. This technology has been re-designed into a reduced length geometry and augmented by inductive charging to permit pulse repetition rates. The antenna is incorporated directly onto the Marx output for efficient energy transfer and for compactness. This package has demonstrated peak electric field strengths up to 4700 V/m at 10m.

Texas Tech University has worked closely with ARC in developing a rapid charging power supply to meet stringent package constraints and still permit high pulse repetition rates. This system has already demonstrated the ability to charge a 50 nF capacitance up to 40 kV with a repetition frequency of 100 Hz, delivering an average power of 4 kW.

This paper details the present status of the project, which will be completed in July, 2005. The cylindrical geometry of the final package has a diameter of 155 mm, a length of approximately 1500 mm without the antenna, and a mass of approximately 35 kg, depending upon the chosen antenna implementation. Results of preliminary tests are included.

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I. INTRODUCTION

The major RF radiation package subsystems are depicted in Figure 1. The control and insulating gas subsystems are briefly outlined below. Those in the right-hand column are discussed separately in more detail in the following sections of this paper.

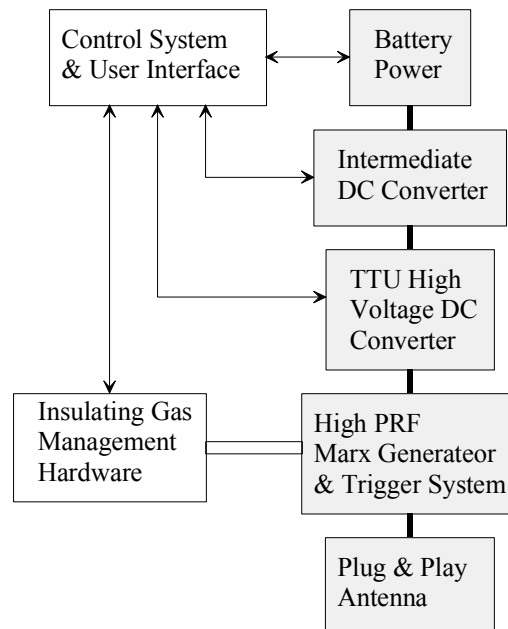


Figure 1. Block diagram of major subsystems.

The control system facilitates a user interface for adjusting operating conditions and monitors system operation. A significant number of the control features have been incorporated into the TTU power supply, where fault conditions are internally monitored and an on-board microprocessor initiates charging scenarios which can be easily reprogrammed by the user.

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The Marx generator requires an insulating gas for operation. For the system shown, breathable dry air at 150 PSI is sufficient for operation. ARC has implemented dry air supporting systems in some of its autonomous systems with a pressure vessel and regulator arrangement. However, the system presented here incorporates a small pump with a desiccant system to remove moisture from the ambient air. Pressure sensors are implemented to control its operation.

II. BATTERY POWER SOURCE

The battery module performance clearly dictates upper theoretical limits to both the maximum average power and overall energy that can be delivered by the high voltage power supply. Competing battery technologies were analyzed, including, lead acid, nickel cadmium, nickel metal hydride, and lithium systems. It was found that the energy storage requirements for several minutes of operation specified a battery pack that could easily deliver ample power for fast discharge versions of all technologies considered.

Therefore, a Power Patrol® SLA1105 12 V, 12 A-hr, high current sealed lead acid battery is chosen for initial operation of the RF package due to cost and simplicity, with a designated battery compartment of 127 mm in diameter and 150 mm in length. Preliminary testing of the combined battery / intermediate DC converter system is presented in the next section.

Future designs will incorporate custom battery modules which can address specific application requirements such as mission duration, mass, shelf life, and temperature characteristics. For example, a high current lithium ion custom battery pack could be constructed for significantly higher energy storage to facilitate longer missions, but it would cost more than an order of magnitude over the lead acid implementation.

III. INTERMEDIATE DC CONVERTER

Power conversion is required to raise the battery voltage up to the TTU high voltage DC converter input level of 200 – 300 V, with a minimum of 250 V being required to sustain 40 kV operation. The intermediate DC converter is designed as a standard H bridge operating at high frequency to drive a transformer. The resulting output is then rectified to achieve a nominal 250 V DC output.

ARC conducted preliminary tests of its intermediate DC converter driving a variable dummy load, while being powered by a number of battery technologies. Figure 2 demonstrates results from the lead acid battery specified in the previous section. For each load condition, the fully charged battery operated the converter until the battery voltage dropped below a threshold of 10.15 V, where the

converter ceased operation. These graphs demonstrate that the battery / converter pair can easily deliver more than 400 W at 250 V for a minimum of 180 seconds and maintain the TTU power supply's 40 kV output. This is an ample time window to demonstrate the RF radiation capability of the package. The converter can sustain an average power of 540 W for tens of seconds

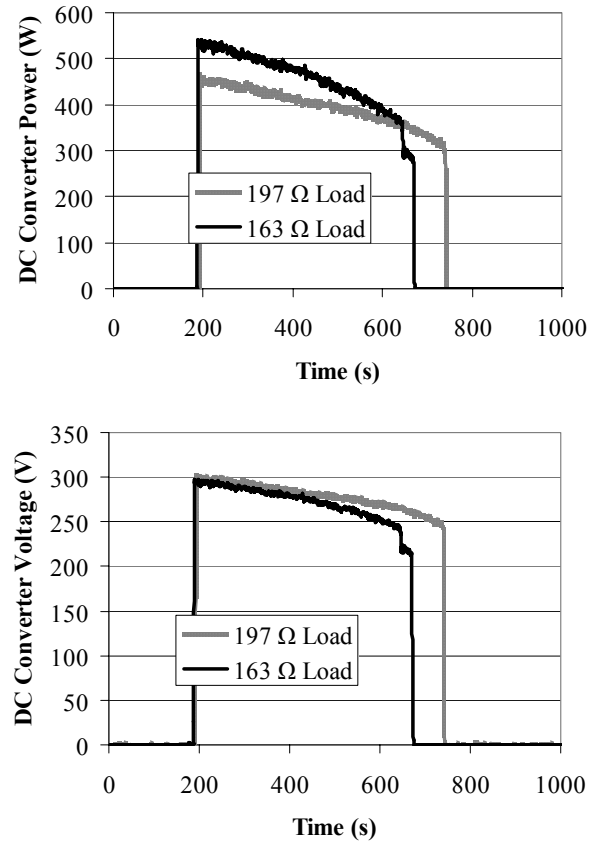


Figure 2. Battery voltage and power with varied loads.

IV. HIGH VOLTAGE DC CONVERTER

The TTU rapid charger is a microprocessor-controlled H-bridge made from Semikron type SKM195GB063 IGBTs which drive the primary side of a high voltage transformer from the 250 V output of the intermediate DC converter. The transformer has six secondary windings to increase its self resonant frequency, which are fed into six high voltage bridge rectifier circuits to achieve its 40 kV output.

The biggest mass and volume reductions from previous designs were achieved by increasing the frequency of operation from 10 kHz to 30 kHz and developing a new transformer with a nano-crystalline core, which was made by Stangenes Industries [1]. This new transformer can be packaged along with its full wave rectifier circuit in a 140 mm ID, 254 mm long

containment structure filled with oil to prevent voltage breakdown. The controller fits into a cylindrical volume of 140 mm with a 178 mm length.

This charger has demonstrated the ability to charge 50 nF of capacitance up to 40 kV at a repetition rate of 100 Hz, which is 4 kW of average power. It can be easily reprogrammed for various output voltages and charge cycle profiles, and monitors itself for fault conditions. Both the transformer and controller, which shown in Figure 3, fit into a volume that is 140 mm diameter and 350 mm in length.



Figure 3. TTU rapid charging power supply.

V. MARX GENERATOR

Marx generators are voltage multiplication circuits where capacitors are charged in parallel and discharged in series. The key to fast risetime and low jitter operation lies in employing stray capacitances to ground to anchor the output side of each switch until switching occurs. This forms a transient wave erection which begins at the triggered switch and cascades down the structure at increasing voltage levels, greatly overstressing the final switches for fast turn-on times [2]. In this way, ARC Marx generators employing spark gap switches and 15 stages of 1 nF ceramic capacitors charged to 30 kV have demonstrated 200 kV pulses into 50 Ω coaxial cable with 250 ps risetimes. Package dimensions for these systems were 75 mm in diameter and 700 mm in length, excluding the power supply.

The Marx incorporated in this package is similar electrically to that described above but is constructed in the 155 mm OD, 610 mm length geometry shown in Figure 4. The Marx utilizes 25 TDK UHV-4A 940 pF capacitors, which are rated for 30 kV but have been demonstrated to operate without problems in an overstressed condition at 40 kV. Spark gap switches are employed, with breathable dry air at 150 PSI as the insulating gas. Inductive charging is incorporated so that

the PRF can be increased from that allowed by original resistive charging.

Each charge cycle requires 19 Joules for capacitor charging. The theoretical maximum PRF 28 Hz, which is limited by the 540 W capability of the intermediate DC converter. The actual maximum PRF has not yet been measured, but is estimated at 20 Hz due to accumulated losses.



Figure 4. Marx generator.

The Marx has already been operated from constant DC high voltage power supplies, with current limiting employed to prevent lock-on of the switches. This problem is alleviated by the TTU power supply operated in a command charge mode, where it is programmed to deliver a specified quantity of energy per charge cycle and then wait until the next cycle is to occur.

The Marx generator delivers 150 kV with a 1.2 ns risetime when driving a 50 Ω load, with a peak power of 425 MW. Results for 40 kV operation should therefore be approximately 240 kV and 1.1 GW when driving a 50 Ω load.

VI. ANTENNA

The antenna is incorporated directly into the end of the Marx to maximize power efficiency and to minimize the overall system volume. Therefore, a plug and play system has been developed which has enabled fast reconfiguration of antenna designs at voltage levels in excess of 200 kV for tens of nanoseconds without breakdown. Only solid dielectrics at ambient pressure are used in this connection to avoid the complexity of oil-filled or pressurized systems

This plug and play system has been incorporated into the RF radiation package for fast reconfiguration to meet application-specific requirements when deployed in the field. A variety of antenna types have been designed and characterized using this method of attachment, including helical and TEM horn configurations.

VII. FINAL PACKAGE

Figure 5 shows the final package design with a helical antenna attached at the output end. The battery pack is inserted into the end of the structure where it is easily accessible for replacement or recharge. All components except the antenna are housed inside of a 155 mm OD, 1500 mm long aluminum cylinder that is with a 4.8 mm wall thickness. The entire package is estimated to have a mass of 35 kg.



Figure 5. Final RF radiation package with all subsystems.

VIII. RESULTS

The radiated waveform of a 1 GHz helical antenna was measured from a ten meter range at two meters above the ground, providing a 2.3 ns time window occurs before the first ground bounce is measured. The radiated signal shown in Figure 6, is typical of a 1 GHz helical antenna driven with ARC's fast risetime pulse generator, achieving a 1500 V/m peak-to-peak signal at 10 m in both the horizontal and vertical polarizations. ARC has demonstrated the ability to generate radiated frequencies from several hundred megahertz up to two gigahertz and bandwidths of approximately 2:1. A 15 cm diameter bicone antenna demonstrated the 4700 V/m at 10 m shown in Figure 7.

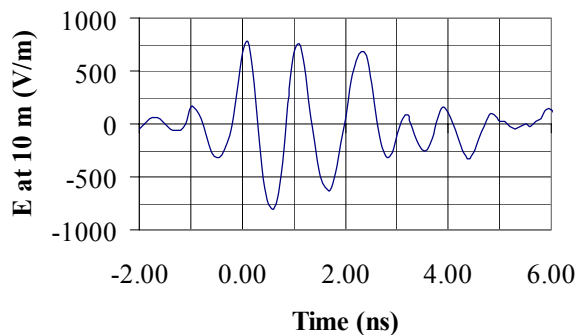


Figure 6. Radiated waveform of a 1 GHz helical antenna.

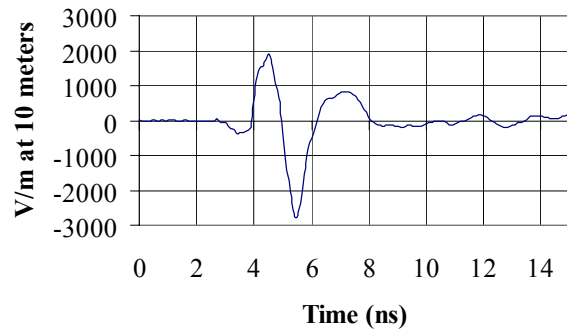


Figure 7. Radiated waveform of a 15 cm bicone antenna.

IX. CONCLUSIONS

The development of an autonomous RF radiation package has been presented and initial tests have been performed on several subsystems. First, the Marx generator has been operated with inductive charging at several Hertz to verify isolation between stages. Second, the plug and play antenna connection has been verified to operate at greater than 200 kV with no voltage breakdown. Third, the TTU power supply has been verified for 40 kV operation and 100 Hz pulse repetition rates when operated from a 250 VDC power supply. Fourth, the battery and intermediate DC converter were operated under load and demonstrated their ability to deliver the required 250 VDC at greater than 400 W for a minimum of 3 minutes, which is estimated to correspond with the Marx generator operating at 20 Hz.

This work is scheduled for completion in July 2005. Future plans are to design and test an upgraded, autonomous RF package with several significant revisions. Plans include redesigning the intermediate DC converter for higher power to facilitate an increased PRF for the package. Also, the mass of the containment structure will be reduced. In addition, a higher energy density battery pack will be designed to better utilize the available volume, maximizing the operational time of the system. ARC will also continue to develop compact antenna structures that can efficiently radiate high peak powers from impulse generators.

X. REFERENCES

- [1] M. Giesselmann and B. McHale, "Rapid Capacitor Charger for 10 Hz Operation of a Low Inductance Compact Marx Generator", 15th IEEE International Pulsed Power Conference, June, 2005.
- [2] W.J. Carey and J.R. Mayes, "Marx Generator Design and Performance", 25th International Power Modulator Symposium, Hollywood, CA, p. 625, 2002